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SECTION IV
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THIRD SERIES—VOLUME LIII—SECTION IV
JUNE, 1959

OTTAWA
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SECTION FOUR

Deformation of the Whitemud and Eastend Formations Near Claybank, Saskatchewan

A. R. BYERS, F.R.S.C.

ABSTRACT

Detailed mapping in the vicinity of Claybank, Saskatchewan, has shown that the Whitemud and the immediately overlying and underlying formations have been isoclinally folded and thrust faulted into a series of subparallel, overturned folds and thrust blocks. A study of aerial photographs indicates that this deformation of the Whitemud is not confined to the vicinity of Claybank but occurs throughout the area of the Dirt and Cactus Hills. The structures are considered to have been produced by the subglacial drag of a Pleistocene ice sheet.

INTRODUCTION

ALTHOUGH the disturbed condition of the Mesozoic strata near Claybank (Figure 1) was noted as far back as 1873 by Bell (1), the complexity of the structures was first brought to the writer's attention by Professor Kupsch during a field trip to the southern part of the province in the autumn of 1957. A cursory examination of the literature showed that similar structures had been noted in Alberta (9; 10) and North Dakota (20), and that there was little agreement among the authors as to the cause of the deformation. Accordingly it was decided to map in detail a small area in order to obtain a better understanding of the nature of the deformation. The area selected, Figures 3 and 4A, lies just south of the Dominion Fire Brick and Clay Products (1954) Limited plant at Claybank. This area was chosen because three clay pits and several large outcrops afforded excellent exposures of the deformed strata.

The mapping was done on a scale of forty feet to one inch by means of plane-table, telescopic alidade, and stadia rod. The topography was contoured at five-foot intervals and geological contacts were recorded to the nearest tenth of a foot. Elevations were tied into a bench mark near the railway station at Claybank. This field work was supplemented by examination of the structures exposed in clay pits at the north end of the Cactus Hills and by a study of aerial photographs covering the area of the Dirt Hills and Cactus Hills, Figure 4 A and 4 B.

The field work which was carried out over a two-week period in the spring of 1958 was made possible through the co-operation of the Saskatchewan Department of Mineral Resources and the Saskatchewan Research Council. The latter also provided funds for the draughting of the maps and figures. W. C. Ross, D. R. Pyke, F. J. Sharpley, and D. L. Delorme assisted

scribed by numerous workers including Williams and Dyer (22) and Fraser of Saskatchewan, were most helpful in suggesting solutions to problems in their particular fields. Mr. R. L. Welch, manager of Dominion Fire and Clay Products (1954) Limited, kindly provided accommodation for the field party in the company's staff house.

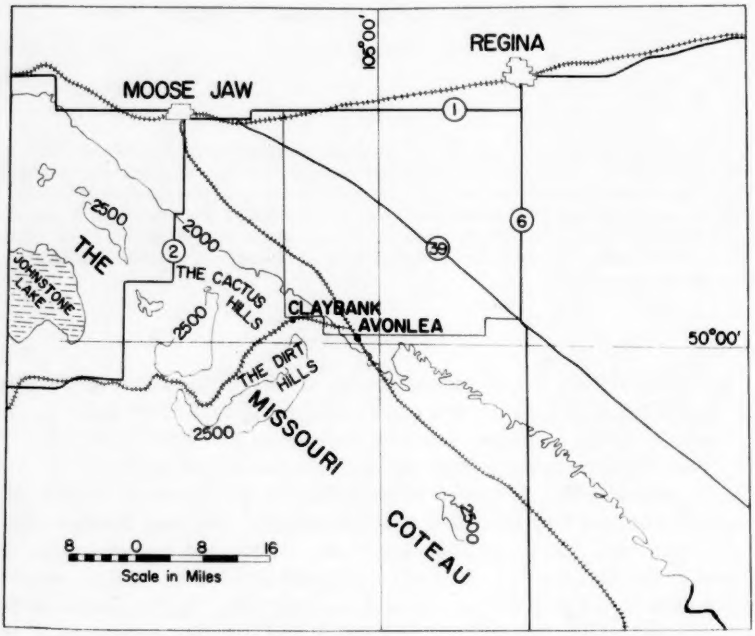

FIGURE 1. Location map of the Claybank area.

GEOLOGY OF THE CLAYBANK AREA

The village of Claybank lies thirty-eight miles southwest of Regina or twenty-seven miles south-southeast of Moose Jaw and is readily accessible by gravelled road from either city. The area which was mapped in detail is one mile southeast of Claybank and covers part of the northern end of the Dirt Hills where they form the northeast flank of the Missouri Coteau, which rises abruptly several hundred feet above the relatively flat Regina Plain to the northeast.

The formations involved in the deformation include the Eastend, Whitemud, and perhaps the lowermost part of the Lower Ravenscrag; all are considered to be of Upper Cretaceous age. They underlie a large part of southern Saskatchewan and southeastern Alberta, and throughout much of this area they are relatively horizontal with regional dips measured in a few tens of feet per mile. Their distribution and lithology have been de-

scribed by numerous workers including Williams and Dyer (22) and Fraser *et al.* (6).

The stratigraphy as measured within the mapped area is shown in Figure 2. The deformation involves a minimum thickness of 208 feet of strata composed of at least 142 feet of Eastend, 54.5 feet of Whitemud, and possibly 12 feet of Lower Ravenscrag. In places Pleistocene ablation till forms a thin superficial mantle resting with angular discordance upon the eroded surface of the deformed older strata. A few remnants of nearly

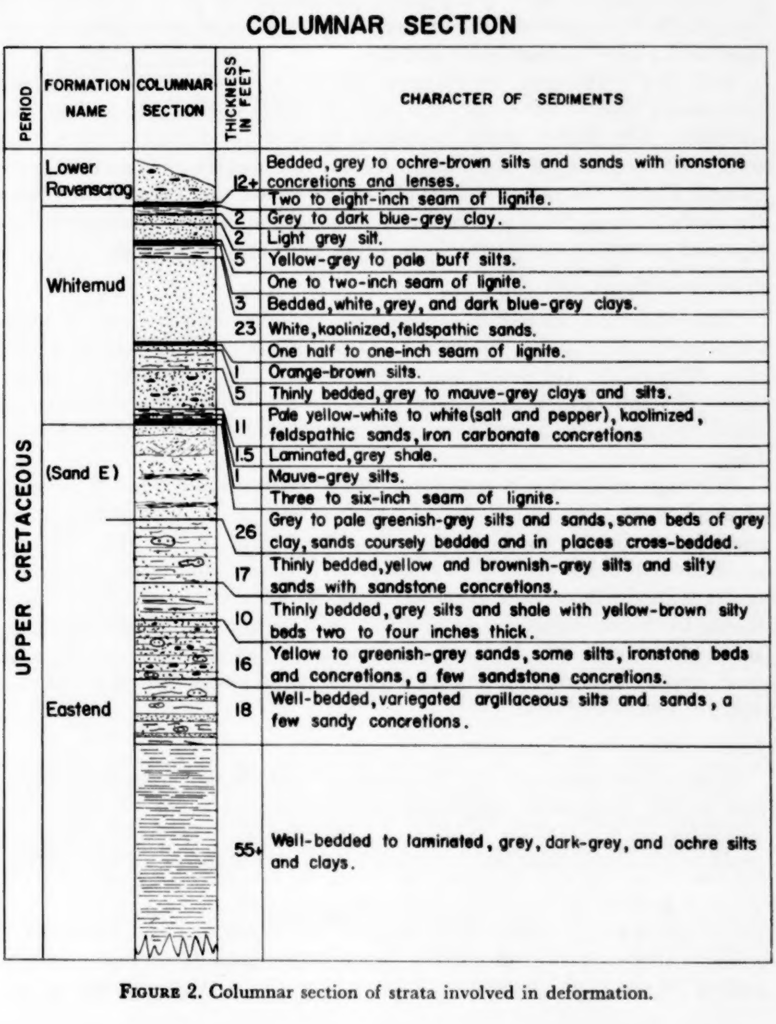

FIGURE 2. Columnar section of strata involved in deformation.

horizontal post-Pleistocene fluvial deposits occur in the lower reaches of the larger valleys.

Eastend Formation

The Eastend formation on the basis of structural behaviour may be divided into three parts: 1. a lower section of 55+ feet composed of relatively incompetent, laminated to thinly bedded, poorly indurated silts, clays, and a few thicker beds of very fine-grained sand; 2. a central portion of 61 feet made up of semi-competent, well-stratified silts and sands with an occasional band of clay; and 3. an upper competent part, Sand E, of 26 feet mainly composed of fine- to medium-grained, massive to thick-bedded sand with a few thin beds of silt and clay.

With few exceptions the incompetent strata of the lower section are compressed into small asymmetric isoclinal folds overturned to the east-southeast. The slightly more competent beds of the middle section form somewhat larger, more open asymmetrical folds which may not be overturned. Finally the upper section of massive sands, Sand E, together with the sandy facies of the Whitemud have behaved competently under deformation and controlled the shape of the larger folds and thrust-fault blocks.

Whitemud Formation

The Whitemud formation, as mapped, includes the refractory to semi-refractory beds of white, kaolinized feldspathic sand and grey to dark grey clays (Figure 2). The lower and upper contacts are marked by distinctive seams of lignite which provide excellent horizon markers for working out the details of the structure. Two other thinner seams within the Whitemud formation also make good marker beds.

Although, as previously mentioned, the Whitemud and Sand E member of the Eastend formation behaved as competent units under deformation, nevertheless there is much evidence to indicate that considerable flow and movement of beds occurred within the Whitemud formation, especially where it forms the central member of the larger overturned folds. This is shown by discontinuous lenses and blocks of lignite and highly contorted lenses of clay and silt which are normally interlayered with the feldspathic sand, and by several of the thicker lenses of lignite which are cut by narrow dykes of feldspathic sand.

Lower Ravenscrag Formation

In two of the structures 6 to 12 feet of silts and sands containing ironstone and selenite concretions appear to rest conformably upon the coal seam which marks the top of the Whitemud formation. As no evidence of faulting could be observed, these beds are shown as Lower Ravenscrag in Figure 2.

Structural Geology

The criteria used in unravelling the structure include horizon markers, such as the seams of lignite at the base and top of the Whitemud formation,

drag-folds, graded bedding, cross-bedding, the shapes and internal structure of concretions, and the position and attitude of fossil lignitized roots. Figure 3 summarizes the structural data and shows major structural elements.

The major structural features are three parallel overturned thrust folds which trend north 15 degrees east and whose axial planes dip at approximately 40 degrees to the west. They are characterized by thrust faults which

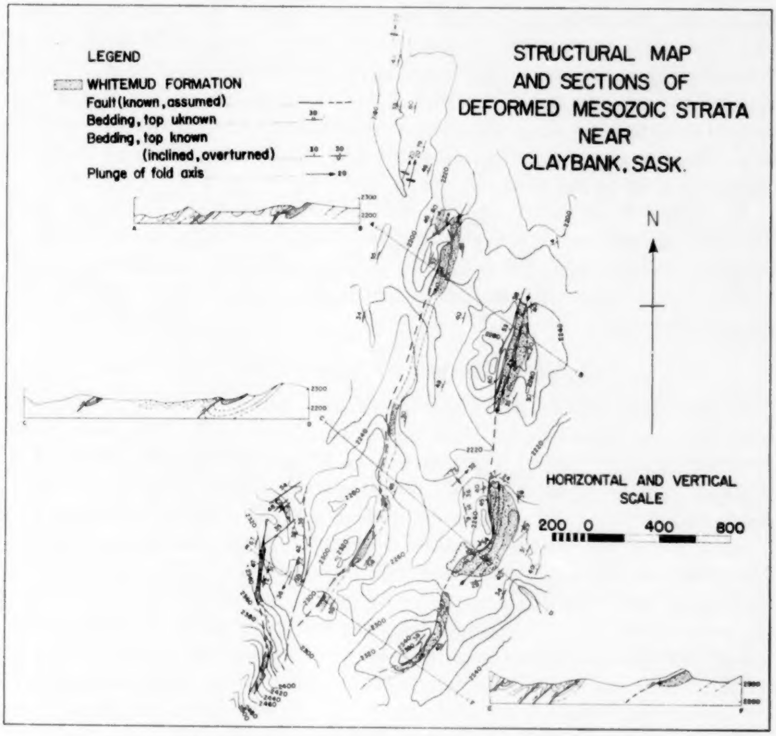

FIGURE 3. Structural map and sections of deformed strata.

also dip west, and by the almost total absence of any trace of an inverted or overturned limb. The Whitemud formation occupies an axial position or forms the upper part of the normal flank of each fold. The beds above the thrust planes belong to the lower and middle sections of the Eastend formation and are contorted into small asymmetrical folds, many of which are overturned to the east. The plunge of individual folds ranges from 20 to 35 degrees and may be either to the north or to the south. Thrust faults which can be followed down dip for any appreciable distance invariably become steeper with depth.

The most easterly of the three thrust folds is the best exposed and shows several culminations and depressions caused by reversals in direction of plunge throughout its mapped length. These cause a separation of the Whitemud formation into three isolated segments which occupy the depressions with the Sand E member of the Eastend outcropping along the culminations.

Estimates of the vertical extent of the deformation must be based on the thickness of the strata involved in the folding and on the projection of the fold structures. As stated previously the minimum thickness of sediments is 208 feet. The maximum visible height of the folds in the outcrops is 356 feet. Reasonable projections of the fold structures both above and below the present surface show the maximum vertical extent to be at least 500 to 600 feet. The dip-slip component of movement on the larger thrust faults is estimated to be in the order of 150 to 200 feet.

According to de Sitter (14, p. 405) overturned folds associated with low-angle thrusts and absence of inverted limbs are characteristic of superficial folds, disharmonically folded on a basement which, in this instance, is considered to be in all probability the Bearpaw shales that underlie the Eastend formation.

Areal Extent of Deformation

To determine the extent of the folded and faulted strata a stereoscopic study of aerial photographs, scale one-quarter mile to the inch, was made covering an area of about 700 square miles (Figure 4 A and B). Figure 4 A is taken from Sectional Map No. 69, Moose Jaw Sheet, scale 1 inch to 3 miles, and modified by omitting the 50-foot contours. Figure 4 B shows the trend of linear topographic features as observed on the aerial photographs. The solid lines show the trend and position of tilted strata as indicated by scarp faces and related dip slopes or by inclination of beds as observed on the sides of valleys. The broken lines represent the trend of topographic linears, ridges, and depressions, which could represent either deformation of stratified drift and non-glacial sediments or undeformed glacial deposits. As the topographic linears parallel the trend of the deformed strata they probably represent deformation of the drift and correspond to the "Stauchmoränen" of Gripp (8).

It is readily apparent from a comparison of A and B of Figure 4 that the trend of the deformed strata corresponds very closely with the general trend of the Dirt Hills and Cactus Hills. Throughout the former the beds dip to the northwest and north or towards the lowland area which forms an embayment into the Missouri Coteau between Claybank and the Cactus Hills. The brief field study of the deformation exposed in the clay pits at the north end of the Cactus Hills showed the deformation to be similar to that at Claybank. However, the folds and faults strike east and the overturning and thrusting is towards the south. On the west side of the Cactus Hills the trend of the deformation follows the margin of a second embayment which

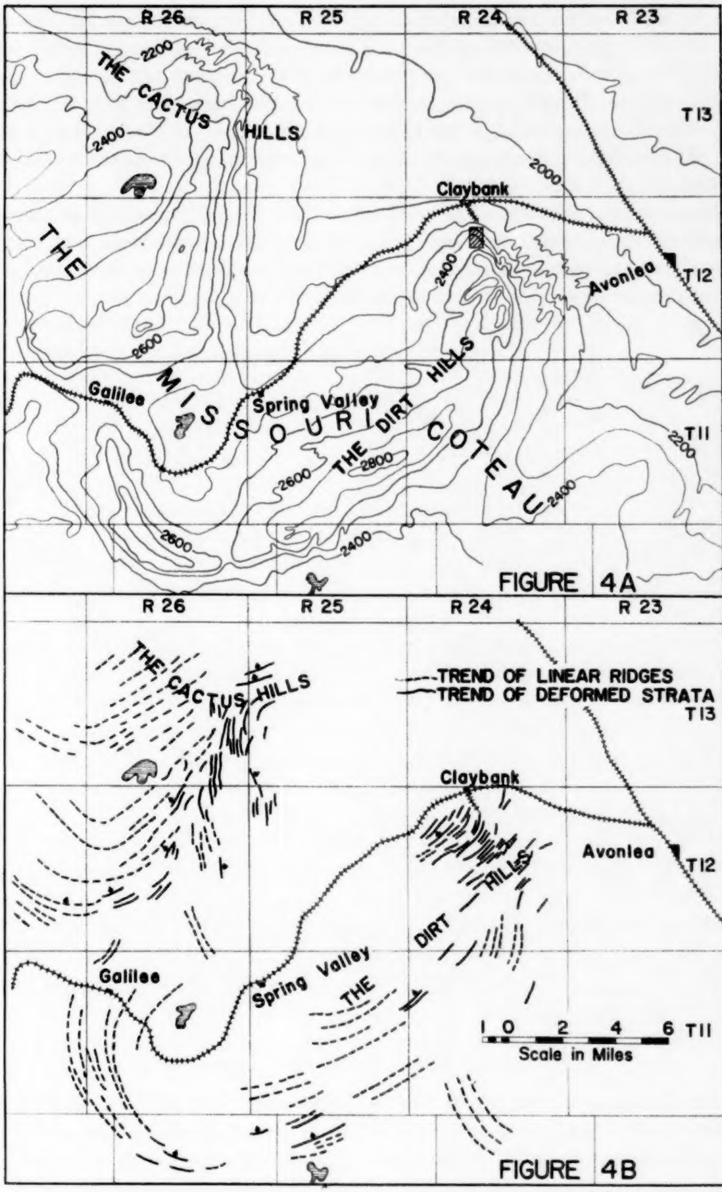

FIGURE 4, A AND B. Topography and structural trends of the Dirt Hills and Cactus Hills area of southern Saskatchewan.

lies betwen the Cactus Hills and the town of Buttress eight miles to the northwest. Again the dip of the beds is towards the lowland. On the east side of the Cactus Hills, however, the dip is to the east, and in the central section the aerial photographs indicate complex folding and high angles of dip. The southeast trend of the topographic lineation in Townships 10 and 11, Range 24, appears to be related to the minor embayment south-southwest of Avonlea.

In summary, the belts of deformation follow the outlines of large embayments extending southward into the northeast flank of the Missouri Coteau. The dip of the beds is mainly towards the lowland areas indicating direction of movement or thrust normal to the sides of the embayments.

Other Areas of Similar Deformation

In the vicinity of Halbrite, eighty-five miles southeast of Claybank, the Eastend and Whitemud strata are very much disturbed and the structures are similar to those at Claybank (Edmunds, personal communication).

Hopkins (9) and Slater (19) describe in detail structures very similar to those at Claybank and involving the Pale Beds of the upper division of the Belly River formation and the overlying Bearpaw shales which outcrop in the Tit Hills (Twp. 39, Range 7, W. 4 Mer.), Mud Buttes (Twp. 33, Range 3, W. 4 Mer.), and Misty Hills (Twp. 32, Range 4, W. 4 Mer.) of Alberta, between 270 and 300 miles northwest of Claybank.

In Burke county, North Dakota, 150 miles southeast of Claybank, similar deformation involving Fort Union (Upper Ravenscrag) strata has been described by Townsend (20). The area of deformed beds lies on the northeast side of the southeastward continuation of the Missouri Coteau.

A classic example of superficial deformation associated with glacial deposits and involving as much as 500 feet of Cretaceous beds is given by Fuller (7) in his report on the geology of Long Island, New York. He notes that most of the folds trend approximately east parallel to the north shore of the island, although on the sides of bays lateral thrust by glacial ice has produced folds with north-south axes.

Other well-known examples of superficial disturbances involving preglacial and glacial sediments occur in eastern England (15; 16); in Denmark (17; 18); in the Netherlands (3; 11); and in northern Germany (2; 14, pp. 304–5; 21).

Origin of Structures at Claybank

The majority of geologists are in agreement that the deformation of stratified drift and underlying preglacial sediments is caused by thrust as the surface is overridden by an active glacier. However, there is a marked difference of opinion regarding the origin of the structures which occur in North Dakota, Saskatchewan, and Alberta. The deformation at Claybank has been attributed to: 1. landslides by Bell (1, p. 77), Ries and Keele

(12, p. 84), and Davis (4, p. 66); 2. gravitational gliding by Dyer (5, p. 36); and 3. faulting by Fraser (6, p. 62). Townsend (20, p. 1569) concluded that the deformation of the disturbed beds in North Dakota was due to deep-seated forces or diastrophism. The disturbed condition of the Pale Beds which outcrop in the Misty Hills, Tit Hills, and Mud Buttes of Alberta has been regarded by Hume (10, p. 7) as due to swelling of bentonitic beds, thus causing distortion of the overlying strata, which, with combined ease of movement along the slippery surface of the wet bentonitic layers, resulted in gravitational gliding and landslides. Hopkins (9, p. 430) and Williams and Dyer (22, p. 89) consider the structures to be the result of glacial ice-thrust. Slater (19, p. 729) agrees about the glacial origin of the structures, but concludes that they were built up by accretions in the form of thin lenticles of folded and faulted englacial material.

Among the phenomena associated with the deformation and affording a clue to its origin may be mentioned: 1. its maximum development along slopes inclined northward, such as the northeast side of the Missouri Coteau or along the borders of the embayments into the Coteau as between Claybank and the Cactus Hills; 2. its minimum development or entire absence over relatively flat surfaces, such as the Regina Plain; 3. its presence well back from the main escarpment of the Missouri Coteau; 4. its superficial nature as shown by seismic records, logs of bore-holes, and data from outcrops; 5. the folds are characterized by low-angle thrusts and by the absence of an inverted limb; 6. the thrust planes steepen at the rear of the folds; and 7. the direction of movement or thrust is normal to the margins of the embayments.

All of these associated phenomena can be readily accounted for by the glacial theory but not by the other theories. Landslides can be discounted as the deformation is not confined to the immediate area of an escarpment. Gravitational gliding is not the answer as the deformation lacks the characteristics of gliding structures such as a thickening of the inverted flanks of the folds and an upward curve of the basal thrust planes (14, p. 289). The superficial nature of the deformation rules out any explanation involving diastrophism or orogenic movements.

The structures produced by ice thrust have been classified by Slater (15, p. 508) into two distinct types. The first is produced by frictional drag of the ice over the underlying beds, producing thrust faults and overturned folds. The second type is acquired by the sediments while incorporated in the moving ice and preserved throughout the period of wastage of the ice. There is no evidence of any englacial material incorporated with the deformed Eastend and Whitemud beds and, therefore, it may be assumed that the structures have been produced by frictional drag.

The cause of the localized nature of the deformation is probably to be found partly in the thickness of the ice sheet, partly in topographic conditions, and partly in the rate of ablation. It is significant that the structures are best developed wherever an escarpment or topographic slope opposes

the direction of ice movement. Recent studies of present glaciers (13, p. 645) indicate that a floor sloping opposite to the direction of motion and a decreasing velocity outward towards the margin of the ice are favourable to the development of compressive flow which takes place partly by basal slippage or boundary-layer flow and partly by internal flow. The component of stress transmitted to the material beneath the ice should increase as the angle of slope increases. The direction of flow is normal to the margin of the glacier which in a lobe would be radial. The embayments on the northeast flank of the Missouri Coteau would initiate and control the position of glacial lobes during the advance and retreat of a main ice sheet to the north. Thus the direction of motion would be normal to the sides of the embayments, and this would account for the arcuate trend of the belts of disturbed strata.

Summary and Conclusions

The observations made by the writer and the conclusions arrived at may be summarized as follows: 1. The structures near Claybank are overturned folds characterized by low-angle thrust faults typical of disharmonic superficial folding. 2. The structures involve a minimum of 208 feet of Upper Cretaceous strata and the amplitude of the folds is estimated to be in the order of 500 to 600 feet. 3. The deformation occurs in arcuate belts which parallel the margins of embayments which extend into the escarpment of the Missouri Coteau which faces northeast. 4. The deforming stress is considered to be due to basal slippage or boundary-layer flow of glacial ice within lobes which occupied the embayments. 5. Similar deformation of unconsolidated strata may be expected to occur throughout the prairie provinces wherever a reverse slope opposes the direction of glacial movement.

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SECTION FOUR

Evolutionary Trends Within Gastroplitan Ammonoids

P. S. WARREN, F.R.S.C., AND C. R. STELCK

ABSTRACT

Middle Albian *Gastroplites* descended from cosmopolitan *Beudanticeras*-like ammonites (*Cleoniceras*) and developed local genera such as the Upper Albian *Neogastroplites* and the Lower Cenomanian *Irenicoceras*. Relationships are postulated with allied genera such as *Lemuroceras*, *Subarctoplites*, *Freboldiceras*, *Tetrahoplitoides*, *Metasigaloceras*, and some members of the *Acanthoceratidae*. Extreme pliability within Gastroplitan morphology permitted adaptation throughout varying palaeoecological regimes.

GASTROPLITES and *Neogastroplites* form a local race of ammonites in Western Canada. Unfortunately, their ancestry is obscured by an excess of taxonomy. The writers consider that the immediate ancestor of the late Middle Albian *Gastroplites* McLearn is a strongly ribbed member of *Cleoniceras* Parona and Bonarelli midway between *Subarctoplites* Casey and *Cleoniceras* s.s.

But the type species of *Subarctoplites* is *Lemuroceras belli* McLearn which is included by Crickmay (4) under his genus *Coloboceras* (*non* Troeussart, 1889, an arachnid) which is an invalid homonym and which has been replaced by *Tetrahoplitoides* Casey (2). The latter has as its type species *Sonneratia stantoni* Anderson which Imlay and Reeside (6, p. 237) suggest to be representative of *Gastroplites*. Other Western Canadian species assigned to *Lemuroceras* by McLearn are variously placed by the writers as follows: viz. *Lemuroceras mcconnelli* (Whiteaves) is a *Subarctoplites* very close to a species of *Cleoniceras*; the latter shows a marked affinity to small specimens of *Beudanticeras glabrum* (Whiteaves) which lack the interruptions of growth (see 13, Pl. 30, Fig. 1). *Lemuroceras irenense* McLearn may well belong to Imlay's new genus *Freboldiceras* but the latter shows a slightly more reduced suture than the former. The form figured by McLearn (9, Pl. V, Fig. 4) as *Lemuroceras* cf. *indicum* Spath is undoubtedly a species of *Arctoplites* Spath.

Certain of the forms referred to *Gastroplites* by Warren (13, Pl. 29, Figs. 8, 9, 11) may be assigned to *Pseudosonneratia* Spath and another (Pl. 29, Fig. 10) to a large, probably new, species of *Subarctoplites*. The specimen questionably referred to *Pusozia* by Warren (Pl. 29, Figs. 6, 7) may be referred to *Uhligella* as it has the same simplified suture. The form *Placenticeras liardense* Whiteaves is placed with *Gastroplites*.

As Casey (2) points out, *Lemuroceras* Spath does not occur in the boreal sphere but there is little question in the writers' minds that Indian *Lemuroceras* are a southern offshoot of the *Cleoniceras* stock that also gave rise to the

northern *Subarctoplites*, the Pacific *Tetrahoplitoides*, and probably the Russian *Cymahoplites*.

In searching for an ancestor for *Gastroplites* certain ontogenetic features of that genus are critical: firstly, the innermost whorls are smooth and obese and reminiscent of *Desmoceras*; secondly, the introduction of ribs is lateral,

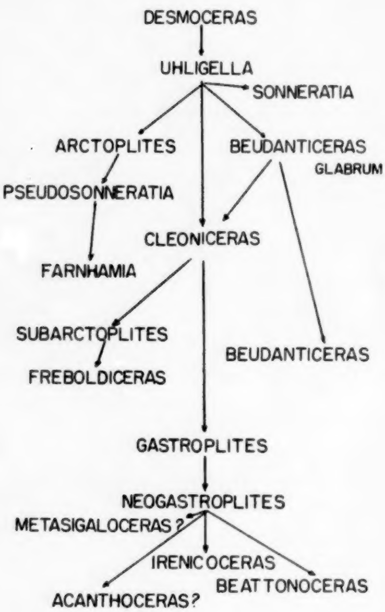


PLATE I: PHYLOGENY OF GASTROPLITAN AMMONOIDS

springing from the umbilical margin by growth line bundling and not crossing the rounded venter; thirdly the ribs are tangential at the umbilical margin at maturity and have such a feature in the early stages. All these nepionic and neanic features are Cleoniceratid.

Cleoniceras is cosmopolitan and is believed to be the ancestral stock for several ammonite lineages which became isolated in Middle Albian time. The Middle Albian ammonite stock known from Alberta contains *Cleoniceras*, *Beudanticeras*, *Subarctoplites*, *Freboldiceras*(?), and *Gastroplites*. But the Middle Albian sea in Alberta is known to have invaded from the Arctic and the southern shoreline of this sea is contained within northeastern British Columbia and central Alberta. It is necessary to seek a boreal ammonite stock to provide the immediate ancestor to both *Subarctoplites* and *Gastroplites*.

From the Arctic realm of continental Canada in the collections of the

University of Alberta there are Lower and Middle Albian specimens assignable to *Desmoceras*, *Uhligella*, *Wollemanniceras*, *Sonneratia*, *Pseudosonneratia*, *Arctoplites*, *Farnhamia*, *Subarctoplites*, *Beudanticeras*, and *Cleoniceras*. Canadian forms that are morphologically similar to *Subarctoplites* such as *Tetrahoplitoides* and *Cymahoplites* are recorded only from the Pacific realm (Queen Charlotte Islands).

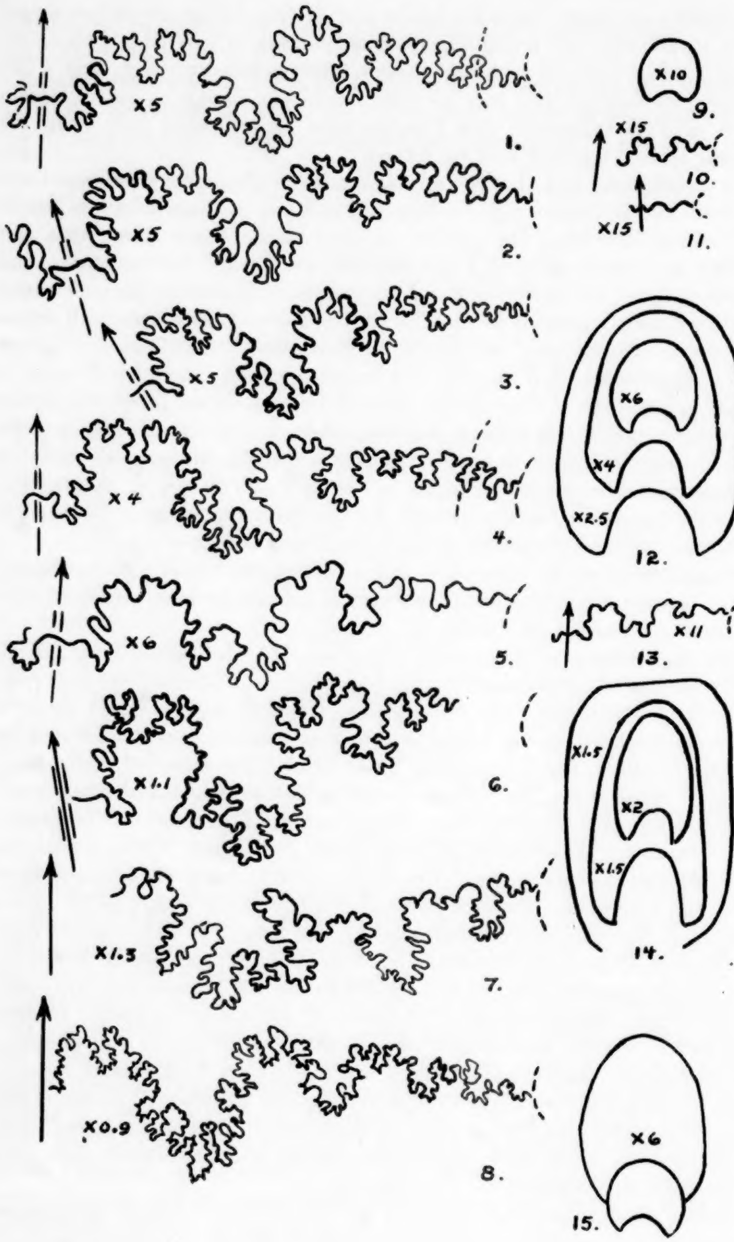
A recent paper by Imlay (5) on Alaskan forms implies an admixture there of both Pacific Ocean and Peace River (Alberta and northeastern British Columbia) elements. The genera common to the Peace River area and Alaska are: *Beudanticeras*, *Cleoniceras*, *Freboldiceras*, *Subarctoplites*, and "*Gastroplites*." Of the above, *Beudanticeras* and *Cleoniceras* are widespread but an anomaly appears in that, in Alaska, *Cleoniceras* comes both below and above "*Gastroplites*" whereas in the Peace River area *Cleoniceras* comes below *Gastroplites* and they are not found together. There is, however, a near-homeomorph of *Gastroplites kingi* McLearn from the lower Mackenzie River area which has a more complex suture and a different ontogenetic development which might properly belong within the stratigraphic range of *Cleoniceras*. The writers recognize as yet only one species of *Gastroplites* from the Canadian Arctic slope and that is a form very close to *Gastroplites liardense* (Whiteaves) which we consider Upper Albian in age.

Examination of the above lists shows that of the forms so far collected only *Cleoniceras* has the shell morphology to provide the inner whorls of both *Subarctoplites* and *Gastroplites*.

An examination of the sutures (see Plate II) of *Beudanticeras* aff. *B. glabrum* (Fig. 3), *Subarctoplites mcconnelli* (Fig. 2), *Subarctoplites*(?) sp. (close to *Cleoniceras*) (Fig. 1), and *Subarctoplites belli* (Fig. 4) shows a common similarity to the *Cleoniceras devisense* Spath suture illustrated by Spath (10, Pl. 4, Fig. 7) from the lower Gault. The suture of *Gastroplites* (Fig. 5) shows a simplification but no reduction in elements of suture compared to the *Cleoniceras–Subarctoplites* pattern. The suture of *Neogastroplites cornutus* (Whiteaves) (Fig. 6) from the Upper Albian shows the restoration of the earlier complexity to the suture without much modification from the *Cleoniceras–Subarctoplites* line although the suture of the inner whorls of *Neogastroplites* passes through the simplified *Gastroplites* stage.

The suture of *Neogastroplites septimus* Warren and Stelck from the Lower Cenomanian (Fig. 7) has a lower profile but corresponds fairly well to the Upper Albian pattern. The suture of *Beattonoceras ontkoi* Warren and Stelck (Fig. 8) mimics the Upper Albian *Neogastroplites* sutures except for the extent of the ventral lobe itself which is not very well known. *Irenicoceras* Warren and Stelck has a suture that reflects the lowered profile of the Cenomanian *Neogastroplites* although matching in pattern the Albian *Neogastroplites*. If sutures show genetic relationships, the *Gastroplites* stock from *Cleoniceras* to *Beattonoceras* is monophyletic.

Whorl sections of *Gastroplites* (Figs. 14 and 15) show a progressive flattening of the sides and venter with growth and for illustration we have


X5
1.
X10
9.
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11.
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X1.1
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X1.5
X2
X1.5
X1.3
7.
14.
X0.9
8.
X6
15.

selected a species that delays this ventral flattening until a late stage. In *Subarctoplites* (Figs. 9 and 12) the conch follows through to a subquadrate section in maturity but never loses the rounding of the venter. However, in some *Gastroplites* as in some *Cleoniceras* there are mature species with a smooth ultimate whorl and in these the venter once again becomes rounded and this stage gives a homeomorph of *Beudanticeras*. Smooth *Neogastroplites* can usually be distinguished from *Beudanticeras* by the retention of the rostrum on the aperture but the smooth *Beattonoceras* is easily mistaken for *Beudanticeras*. We also have in our collections *Gastroplites* that are near-homeomorphs of *Cymahoplites*.

The writers have found considerable difficulty in making generic references because of homeomorphy in ribbing patterns in the adult stage of different lineages. In sharp contrast to this problem of convergence we are faced with intraspecific variation. The late J. B. Reeside, Jr. (personal communication), while studying *Neogastroplites* found multiple heteromorphic series within each of several species of that genus. Such pliability of form is also suggested in some measure for the genus *Gastroplites*, as many "species" may be collected from a single nodule. In earlier beds, species of *Subarctoplites* may be found showing a varied delay in the introduction of ribbing. Warren (13, Pl. 30, Figs. 3 and 4) figured a "*Beudanticeras*" *glabrum* showing *Cleoniceras*-like ribbing on one side, but this feature is lacking on the other side of the same specimen.

Similarly *Gastroplites* shows variation of involution, as the width of the umbilicus in *Gastroplites allani* McLearn is one-sixth of the diameter,

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PLATE II: GASTROPLITAN SUTURES AND WHORL SECTIONS

FIG. 1. *Subarctoplites* sp. (×5) ct. 1159 a, U. of A. external suture at whorl height 13 mm., from specimen showing late introduction of ribbing after diameter of 25 mm. from Loon River formation, Peace River, Alberta. FIG. 2. *Subarctoplites* cf. *S. mcconnelli* (Whiteaves) (×5) ct. 1159 b, U. of A. mirror image of external suture at whorl height 12 mm. from specimen showing early introduction of ribbing before 4 mm. diameter. from same nodule as above. FIG. 3. *Beudanticeras* cf. *B. glabrum* (Whiteaves) (×5) ct. 1159 c, U. of A. external suture at whorl height 14 mm. from unribbed specimen, from same nodule as above. FIGS. 4, 9–12. *Subarctoplites belli* McLearn from upper part of Loon River formation, Peace River, Alberta; 4, ct. 1160 a, U. of A. mirror image of external suture at whorl height 15 mm. (×4); 9, ct. 1160 b, U. of A. whorl section (×10) at 1 mm. height; 10, 11, external suture of same (×15) at whorl height 1 mm. and 0.4 mm.; 12, ct. 1160 a, U. of A., whorl sections at heights 2.5 mm., 7 mm., 16 mm. (×6, ×4, ×2.5) respectively. FIGS. 5, 13–15. *Gastroplites* sp. Cadotte sandstone, near Gates on Peace River, British Columbia, ct. 1161 U. of A.; 5, external suture at whorl height 10 mm. (×6); 13, external suture at whorl height 1.9 mm. (×11); 14, whorl sections at height 9 mm., 22 mm., 26 mm. (×2.0, ×1.5, ×1.5); 15, whorl sections at heights 1.7 mm. and 3.9 mm. (×6). FIG. 6. *Neogastroplites cornutus* (Whiteaves) external suture at whorl height 58 mm. (×1.1) after McLearn, 1933, Plate 4, St. John Shale, below fish scales, Peace River, British Columbia. FIG. 7. *Neogastroplites septimus*, Warren and Stelck, ct. 1134 U. of A., external suture at whorl height 75 mm. (×1.3) St. John shale, above fish scales, Peace River, British Columbia. FIG. 8. *Beattonoceras ontkoi* Warren and Stelck, ct. 1131, U. of A., external suture at whorl height 85 mm. (×0.9), St. John shale above the fish scale sand, Peace River, British Columbia.

whereas, in *Gastroplites anguinis* McLearn it is one-third. The same range may be noted within forms assigned to one species viz. *Gastroplites canadensis* (Whiteaves). *Gastroplites anguinis* has about the same involution as *Lemuroceras* whereas *Gastroplites allani* has about the same involution as *Subarctoplites*. In our opinion, this variability is an expression of their potential adaptability to varying ecological conditions. This may well be the reason why *Gastroplites* stock was the only ammonite lineage to maintain itself from the Middle Albian to Lower Cenomanian stage in the Peace River area of Western Canada.

The history of the late Albian seaways in Western Canada has been treated previously by the junior author (12). In brief, the early Albian boreal sea was confined to the Arctic slope but an embayment developed which reached as far south as central Alberta by Middle Albian time. This embayment was separated from the Pacific Ocean by the land mass of Cordilleran British Columbia and the Yukon and a cosmopolitan aspect pertains only to the Lower Albian forms and not to those of the Middle Albian. No Middle Albian species of ammonites is common to both the interior embayment and the Pacific coast. By Upper Albian time the south end of the Arctic embayment became a landlocked sea (Mowry) that covered most of northeastern British Columbia, Alberta, southern Saskatchewan, eastern Montana, the Dakotas, Wyoming, Nebraska, and possibly Colorado.

As far as can be determined the boreal link was broken during the development of *Gastroplites*. It was established briefly in *Gastroplites liardense* time, as *Gastroplites* appeared briefly in northern Yukon (and Alaska?) and reached England. For the remainder of Upper Albian time it was an interior sea and in the Cenomanian finally connected with the southern flooding from the Gulf of Mexico. The Gastroplitan stock of ammonites disappeared when the waters regained oceanic coalescence in Upper Cenomanian time.

It is questionable whether a lineage as vigorous as the *Gastroplites* stock could easily be extinguished. It persisted through varying salinities, and from open sea to euxinic and landlocked basinal conditions, and maintained itself during intermittent connections with Arctic, Gulfian, and perhaps Atlantic waters. During the period of transition from Lower to Upper Cretaceous, the *Neogastroplites* group of ammonites developed a wide variety in form, size, and ornament. Their size is known to range from about half-an-inch in diameter to large discs measuring eighteen inches across. The shape of whorl section ranges from globose to lenticular with some quadrate forms. Ornament ranges from ribbed to smooth, bullate and clavate forms, and forms with and without siphonal nodes.

Such a multiplicity of morphologic characters is apt to give rise to a corresponding multiplicity of discrete lineages, if stabilized. The writers suggest that many of the "orphan" genera of late Cenomanian time may have a vigorous parentage within *Neogastroplites* s.l. Certain forms like *Metasigaloceras*(?) (Hyatt) figured by Warren and Stelck (14) from the

Lower Cenomanian of northeastern British Columbia could be congeneric or at least ancestral to that genus. The species they figure has definite connection with *Neogastroplites*. Cenomanian *Neogastroplites* tend to have simple ribs on the outer whorl although branching ribs appear on the inner whorls. This gives the conch an appearance of an involute *Acanthoceras*.

The ancestry of the family Acanthoceratidae which has been attributed to *Lyelliceras* could as easily be attributed to an evolute *Neogastroplites*. *Lyelliceras* carries alternate and not opposite lateroventral nodes. Since *Neogastroplites* often carries siphonal nodes we feel that it represents a more logical ancestor for many of the Acanthoceratids.

The external homeomorphy of *Gastroplites liardense* to genera like *Irenicoceras*, *Stoliczkaia*, *Utaturiceras*, and *Metoicoceras* is obvious. The relationship of these to *Neogastroplites* is not as obvious but may be more pertinent. Such North American genera as *Budaiceras* and even *Dunveganoceras* may have an origin in evolute Neogastroplitids. *Acanthoceras athabascense* Warren and Stelck may have the same heritage. The writers have long speculated that *Ammonites glossonotus* Seely from England is actually a *Neogastroplites* and not a malformed *Callihoplites* as suggested by Spath (10, p. 224). Seely's type came from the Cambridge Greensand, a bed correlative with the "fish scale" horizon of Western Canada at the contact of the Upper and Lower Cretaceous. These are the beds where the *Gastroplites* stocks showed maximum evolutionary explosion as exemplified by *Neogastroplites* itself.

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SECTION FOUR

Evolution of the Mississippian *Lithostrotion mutabile*-*Lithostrotion whitneyi* Coral Group of the Southern Canadian Rockies

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Presented by P. S. WARREN, F.R.S.C.

ABSTRACT

The evolutionary history of the Mississippian fasciculate corals *Lithostrotion mutabile* (Kelly), *L.* n. sp., *L. whitneyi* Meek, and *L. arizelum* (Crickmay) is suggested. Usually, evolution of the group has been towards increase in corallite size, accompanied by increase in number and length of major septa; also accompanied by increase in tabular inclination, number of dissepiments, and width of dissepimentarium. Longitudinal patterns of structures of juvenile corallites of one horizon usually mimic structures of species of the preceding horizon.

Introduction

This paper describes the possible evolutionary history of fasciculate corals belonging to *Lithostrotion mutabile* (Kelly), *L.* n. sp., *L. whitneyi* Meek and *L. arizelum* (Crickmay). These corals occur in the Mississippian System of the southern Canadian Rockies. Stratigraphic range and diagnostic features of each species are shown on Figures 1 and 2.

The Mississippian System of the southern Canadian Rockies is represented by four formations. The lowest is the Banff formation which comprises between 1,000 and 1,500 feet of recessive dark argillaceous carbonates. The lower part of this unit is Kinderhookian and the upper part Osagean (probably Burlington) in age. The Banff formation is overlain by the Rundle group which, in ascending order, consists of the Livingstone, Mount Head, and Etherington formations. The Livingstone generally contains from 1,000 to 1,500 feet of resistant, light-coloured crinoidal limestone alternating with fine-grained carbonates. It is Osagean in age and may be equivalent to the Keokuk limestone of the Mississippi Valley. The Mount Head formation is a recessive unit of mainly Meramecian age and generally comprises about 500 to 600 feet of argillaceous carbonates and shales. The Etherington is a fairly light-coloured unit of mainly resistant limestones and dolomites. The thickness is variable: in most areas it is between 400 and 600 feet. The formation is mainly Chesterian but may contain some Pennsylvanian strata. For further information on stratigraphy the reader is referred to Kindle (6), Warren (13), Beales (1), Douglas (3), Douglas and Harker (4), Raasch (11, 12), Moore (7), Nelson (8, 9), and Nelson and Rudy (10).

The evolution of the *L. mutabile–L. whitneyi* group in general has been towards increase in corallite size accompanied by an increase in length and number of major septa, tabular inclination, number of dissepiments, and width of dissepimentarium. Longitudinal structures may be important in suggesting the history of the group because juvenile corallites appear to mimic structures of mature corallites of species of the preceding horizon.

Description of Species and Suggested Evolution

The oldest known species of the group, *Lithostrotion mutabile* (Kelly), ranges from the upper 300 feet of the Banff formation into the lower 100 feet of the Livingstone formation. Corallites are generally between 5 and 7 mm. in diameter and have short major septa. Tabulae are nearly flat over most of the interior but strongly deflected downwards near the periphery. Dissepiments occur either sporadically in a single row or are lacking.

Lithostrotion n. sp., the next species of the group to appear, has an extremely restricted range. So far as is known it occurs only in the basal 50 feet of the Mount Head formation. Externally it is very similar to *L. mutabile* although a few colonies have larger corallites with a diameter between 8 and 9 mm. Longitudinal sections of mature specimens of *L.* n. sp., however, are different in that tabulae are more inclined and have much less pronounced marginal deflection. Dissepimental pattern is the same as in *L. mutabile*. Good longitudinal sections of juvenile corallites were so difficult to obtain that the writer feels that little stress should be placed on their importance in determining the relationship of *L.* n. sp. to *L. mutabile*. A section of a juvenile corallite (Fig. 1b) has a tabular pattern similar to that of mature *L. mutabile* but does not show such pronounced marginal downwarping.

Both *Lithostrotion mutabile* and *L.* n. sp. are similar in many respects and it would seem reasonable to suppose that the latter was derived from the former. However, the two species are separated by an unfossiliferous interval of the Livingstone formation comprising between 1,000 and 1,200 feet. At first glance this great thickness suggests a relatively large amount of geologic time so that *L.* n. sp. may have been indirectly rather than directly derived from *L. mutabile*. The writer, however, considers that the time span of the Livingstone is relatively short and that the evolution may have been direct. The short time span is suggested by the fact that over two-thirds of the Livingstone formation in the Banff area is crinoidal limestone —sediments which probably are deposited rapidly. Additional evidence for the short time span is suggested by temporal equivalents of the Livingstone to the north in the Jasper area. Here they are only about 300 to 400 feet thick and consist mainly of apparently conformable, very fine-grained carbonates.

As noted previously, *Lithostrotion* n. sp. has an extremely restricted range. An extensive search has shown no sign of the species in higher beds of the fossiliferous Mount Head formation. Since the normal range of Mississippian

coral species is about 300 feet it is possible that the lower range of the species may be in the unfossiliferous Upper Livingstone. If this be so then the lower range of *L.* n. sp. is closer to the upper one of *L. mutabile* than is apparent from the fossil occurrence.

Lithostrotion whitneyi Meek of middle and upper Mount Head clearly appears to be derived from *L.* n. sp. The species has larger corallites, between 9 and 13 mm. in diameter, and proportionally longer major septa than *Lithostrotion* n. sp. Longitudinal sections of mature corallites show that the tabulae are fairly flat, being deflected upward near the columella and down-

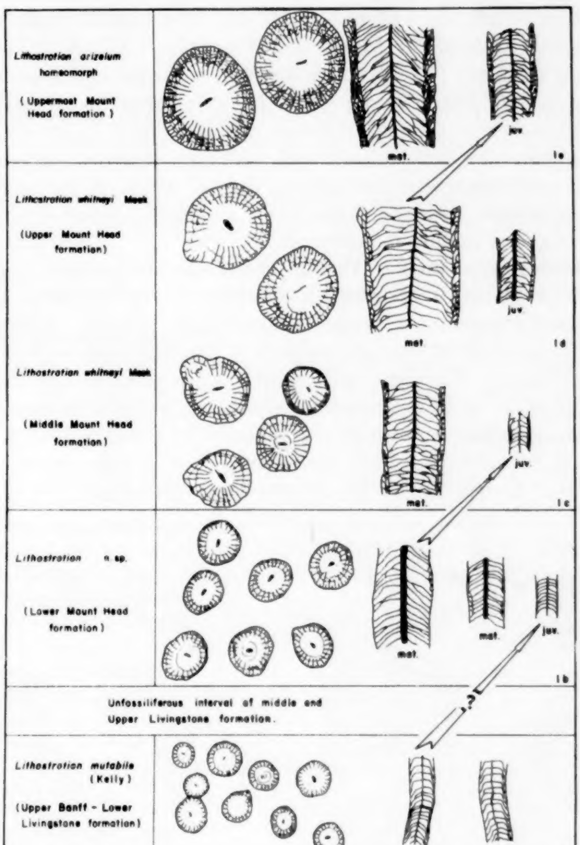

FIGURE 1. Suggested evolution of the *Lithostrotion mutabile–L. whitneyi* group. Transverse sections are shown on the left and longitudinal ones on the right; all natural size. Juvenile longitudinal sections of *Lithostrotion* n. sp. and *L. whitneyi* (middle Mount Head) are taken from sketches. All other illustrations, including those in Figure 2, are taken from photographs.

ward near the periphery. Longitudinal sections of juvenile *L. whitneyi* are very similar to those of mature *L.* n. sp. in that tabulae are inclined upward.

A fair degree of tolerance has been used in establishing the limits of *L. whitneyi* for there seems to have been a minor evolution within the species. *Lithostrotion whitneyi* of middle Mount Head generally have smaller corallites and fewer major septa than those from the upper part of the formation. The youngest specimens of *L. whitneyi* are almost gradational into the immediately overlying *L. arizelum* homeomorphs in that ephebic stages (not shown on Fig. 1) sometimes have rather steeply inclined tabulae and a wide dissepimentarium with three or four rows of dissepiments.

Specimens which the writer calls "*L. arizelum* homeomorphs" occur in the uppermost beds of the Mount Head formation (Figs. 1e, 2a). These have larger corallites (12–18 mm.) than *L. whitneyi* and more numerous and proportionally longer major septa. The most pronounced difference between the two is found in mature longitudinal sections: *L. arizelum* homeomorphs have a wider dissepimentarium, with numerous rows of dissepiments, and much more steeply inclined tabulae than *L. whitneyi*. Juvenile *L. arizelum* homeomorphs, however, have gently inclined tabulae very similar in pattern to those of mature *L. whitneyi*.

The taxonomic position of the *L. arizelum* homeomorphs is uncertain. The type specimens of *L. arizelum* (Crickmay) s.s. are from the lower Mount Head formation at Lake Minnewanka, Alberta (Crickmay, 2). Mature specimens of this species are almost identical with mature *L. arizelum* homeomorphs of uppermost Mount Head (compare Figs. 2a and 2b) but juvenile sections of the former are not available for comparison. The writer considers that *L. arizelum* (Crickmay) s.s. belongs to a different lineage than that discussed here. Intensive collecting both above and below the horizon of *L. arizelum* s.s. has failed to find related forms.

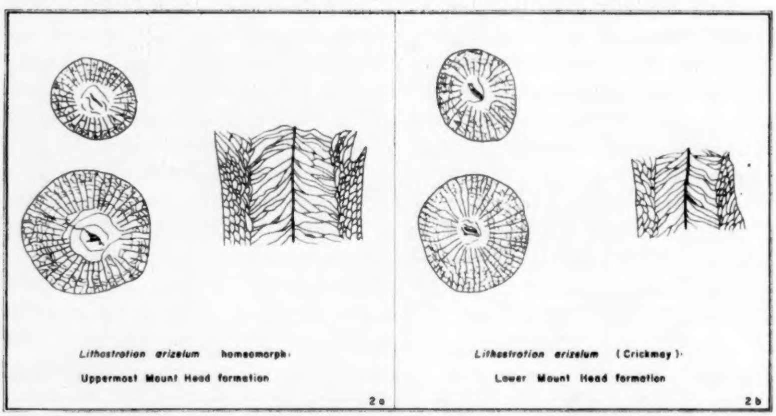

Figure 2. Comparison of the *Lithostrotion arizelum* homeomorph with *L. arizelum* Crickmay s.s. See also Figure 1e.

The writer is hesitant about applying a new name to the *L. arizelum* homeomorphs until sections of immature *L. arizelum* s.s. are available. These homeomorphs are very closely related to, and may be conspecific with *L. proliferum* Hall. Kelly (5), however, has indicated that a septal columella is absent in *L. proliferum*. In all the specimens of *Lithostrotion* discussed here, the columella is related to the counter septum.

No record of the *L. mutabile–L. whitneyi* lineage is preserved in the Etherington formation. The occurrence of the *L. arizelum* homeomorphs in uppermost Mount Head probably represents a first appearance. Their absence from the overlying Etherington is likely due to environmental conditions.

Appendix

Stratigraphic data on specimens illustrated in Figures 1 and 2 (all specimens are deposited in the Department of Geology at the University of Alberta).

Figure 1a: *Lithostrotion mutabile* (Kelly). Hypotype U. of A. no. 341. From rubble of the lower Rundle group at South Ram River, Alberta (Lat. 51° 58′, Long. 116° 07′).

Figure 1b: *Lithostrotion* n. sp. Holotype U. of A. no. 338. From 10 feet above base of the Mount Head formation at Mount Rae, Highwood Pass area, Alberta.

Figure 1c: *Lithostrotion whitneyi* Meek. Hypotype U. of A. no. 323. From between 145 and 153 feet above the base of the Mount Head formation at Mount Rae, Highwood Pass area, Alberta.

Figure 1d: *Lithostrotion whitneyi* Meek. Hypotype U. of A. no. 345. From 410 feet above the base of the Mount Head formation at Mount Norquay near Banff, Alberta.

Figure 1e: *Lithostrotion arizelum* homeomorph. Hypotype U. of A. no. 326. From 490 feet above the base of the Mount Head formation at Mount Rae, Highwood Pass area, Alberta.

Figure 2a: *Lithostrotion arizelum* homeomorph. Hypotype U. of A. no. 327. From near the top of the Mount Head formation (fault slice 4 of Rundle), Crowsnest Pass, Alberta (see 9).

Figure 2b: *Lithostrotion arizelum* (Crickmay). The transverse section is taken from a portion of the holotype, U. of A. no. Cb 563. The longitudinal section is from topotype U. of A. no. 325. Both are from bed 14 (section 2) of the Rundle at Lake Minnewanka, Alberta (see 2).

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SECTION FOUR

Modern Soil Science (Pedology) in Relation to Geological and Allied Sciences

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Presented by F. H. EDMUNDS, F.R.S.C.

ABSTRACT

An introduction to the viewpoint of the pedologist on the nature of the soil and the place of soil science among other earth sciences. To the pedologist the soil is an independent natural body and its study forms a distinct and separate branch of natural science. To explain this concept the soil-forming factors—climate, vegetation, parent material, topography, and time—are discussed briefly and the soil profile is defined. Monoliths of some Western Canadian soils are exhibited. In addition the following suggestions are presented and discussed.

(1) Natural soils should be identified and described according to the methods of pedology.
(2) Geological and related studies of the regolith should take account of pedological aspects.
(3) The soil classification and soil map can be a valuable aid to the interpretation of the geology and geography of a given area.
(4) A wider recognition and use of pedology in other sciences will assist pedological research.

INTRODUCTION

ACCORDING to Dokuchaiev, the founder of modern soil science or pedology, "Soil is an independent natural body which must not be mistaken for the surface rocks" (1). If this statement is accepted it follows that the study of the soil constitutes a distinct and separate branch of natural science, with its own laws and methods. Unless the above views are valid the soil scientist has no place of his own in the world of knowledge.

On the other hand, the acceptance of these ideas does not mean that the older sciences are not needed for the study of soils. On the contrary, the student of today who desires to specialize in pedology should receive basic training in the fundamental sciences of mathematics, physics, chemistry, and biology, and as much training as he can acquire in such fields as general geology, mineralogy, geomorphology, climatology, and plant ecology. Such training is required for the basic studies in pedology—soil morphology, soil genesis, soil geography, and soil classification. The pedologist, therefore, recognizes his dependance on other sciences. In return he would ask workers in other disciplines, when they are concerned with the soil, to make use of the special body of knowledge accumulated in the name of pedology.

This paper is an attempt to show that pedology can contribute to studies

made in other branches of science, and that failure to appreciate this may on occasion limit the value of geological and related work. It is also intended to show that an understanding of soil science by workers in other fields can assist the progress of pedological research.

Before discussing the above topics it is necessary to present a very brief account of the development and the nature of the science of pedology. No attempt has been made to compile a full list of references or to cover the field of applied pedology. In addition to the specific references selected, the following authors are included as valuable sources of information on pedology (7; 9; 10; 11; 15; 16; 18). For Canadian sources the departments of soil science of Canadian universities and the national and provincial soil-survey organizations may be consulted.

The Development of Modern Soil Science

Modern soil science or pedology began about eighty years ago. In 1879 Dokuchaiev presented the first classification of soils based upon features of the soil itself. Prior to this soils had been classified according to their use (notably for agriculture), or according to the physical, petrological, or chemical nature of the surface rocks (13). Moreover, the term "soil" was restricted to the immediate surface layer of the earth which supported plant life. Consequently, no universal body of knowledge concerning the soil could be acquired until the soil was studied for its own sake, regardless of its value or use to man or its place in geological–geographical classifications of the surface rocks (1; 23).

The work of Dokuchaiev and his pupils, Sibirtsev and Glinka, laid the foundation of the Russian school of soil science. The new science spread slowly, partly because of the difficulties in language and partly because of the lack of contact with Russian work. Ramman in Germany was influenced by the Russians. Hilgard, working independently in America, recognized the differences between soils of humid and arid regions; Marbut introduced the Russian viewpoint to North America and added his own contribution to pedology (17). A most important influence on soil investigations in the English-speaking world came in 1927 when Marbut's translation of Glinka's major work was published (7). The first paper from Western Canada to deal with the modern concepts of soil science was contributed by Joel (8).

The main contribution of the Russian workers may be summarized as follows: (1) They defined the factors of soil formation—climate, vegetation, parent rock, relief, and time. (2) They showed that over broad regions and with sufficient time, climate is the most important soil-forming factor. This concept upset the prevailing views held by geologists and geographers, since it showed that similar rocks developed into different soils under different climates and, conversely, rocks of differing origin developed into similar types of soil under the same climate. (3) They formulated a concept of the geographical distribution of major world soils in great zones

or belts corresponding to broad climatic–vegetational regions: tundra, temperate forest, steppe, desert, and tropical forest. (4) They emphasized that the soil is not confined to the surface layer, but includes the whole soil profile—the natural layers or horizons formed by pedogenic forces and extending from the surface down into the parent geological material below. (5) They developed a system for identifying and describing the morphology of the soil profile, and applied it to the study of the soil in the field. (6) They made use of chemistry to throw light on the origin of the soil and as an aid to classification of the soil. Previously, chemical analysis had been used chiefly to determine the composition of the soil from the standpoint of plant nutrition or for the purpose of rock analysis.

Soil Constituents and Soil Formation

Soil Constituents

The major constituents of the soil are: mineral matter and organic matter—the solid phase; soil water—the liquid phase; soil air—the gaseous phase; and living organisms.

The mineral matter consists of rock and mineral fragments ranging in size from stones to clay particles, the latter having a diameter of less than .002 mm. The mechanical composition of the soil is based upon the relative proportions of the different particles. It is a matter of regret that pedologists, geologists, and engineers do not use a common standard for characterizing particle size and textural class.

The organic matter includes raw or undecomposed, partially decomposed, and highly altered organic material. The last is resistant to further change and is termed the humus fraction. The organic matter upon decomposition returns mineral matter to the soil and also acts as a source of energy for the micro-organisms.

The liquid phase is in equilibrium with both the solid and the gaseous phases, but the equilibrium changes with variations in soil temperature, water content, and the activities of living organisms and plants.

The soil water contains various mineral and organic substances in solution. The soil air contains much more carbon dioxide than ordinary air, and this in combination with water supplies the carbonic acid so important in rock weathering and soil formation.

The living organisms include rodents, insects, earthworms, and micro-organisms. The last decompose organic matter and are essential to the production of plant nutrients and to other processes of soil formation.

Soil Formation

It is important to realize that the soil is not a mechanical or inert mixture of its various constituents but a dynamic body. The clay and humus fractions in particular are the reactive constituents. These display the colloidal properties of volume change, plasticity, cohesion, and cation exchange, and they originate chiefly from chemical and biological processes operating

within the zone of soil formation. The clay fraction includes the clay minerals which have been studied so actively in recent years, and which were first identified through studies of the soil.

The formation of soil involves the processes of weathering so familiar to the geologist and also those processes leading to the development of the soil profile. Obviously both processes may proceed concurrently and indeed will do so as long as unweathered but weatherable minerals remain in the soil (15).

As already mentioned the soil profile is a product of the influences of climate, vegetation, parent rock, topography, and time. To these major soil forming factors we may add man and his use or misuse of the soil. The relation of the climatic factor to rock weathering need not be discussed here. In relation to soil development the climate largely determines the type of vegetation, the amount of water available for movement within and through the soil, and the soil temperature. The vegetation is the main source of soil-organic matter. It influences the type of soil development and in turn is influenced by the soil. The parent rock represents the geological parent material in which the soil develops. It is the source of the mechanical composition and the mineral plant-nutrients of the soil. Topography—the relief, slope, aspect, and shape of the land surface—influences local soil climate and drainage. In semi-arid to sub-humid regions very slight variations in topography are associated with important and often striking differences in soil profiles. Time as a factor of soil formation influences the stage of development of the soil profile. Soils may pass from a stage of youth to maturity and even old age. However, the time factor in soil development is not identical with geologic time, since mature soils may be found on relatively young geological deposits, and youthful soils on older deposits. The intensity or vigour of the processes of soil development, as determined by the combined effects of all soil-forming factors, may modify the effect of time alone.

The Soil Profile

The features which distinguish the various layers or horizons of the soil are used to identify and describe individual soil profiles. These features are the colour, structure, texture, thickness, and composition of each horizon. For convenience the main horizons of the soil, from the surface downwards, are designated by the letters A, B, C, and sometimes D.

The A horizon usually contains most of the organic matter of the soil and a large population of micro-organisms. Owing to its position with relation to the earth's surface the A horizon is particularly influenced by the climatic and vegetational factors of soil formation and by the geological factors of weathering, deposition, and erosion. The A horizon is also subject to leaching or eluviation whereby soluble constituents, certain complex organic-mineral compounds, and colloidal material may be transported by the soil water to lower horizons.

The B horizon is situated immediately below the A and part of the material leached from the A horizon is deposited in the B—a process known as illuviation. In addition other changes may occur within the B horizon owing to the processes of weathering and pedogenesis.

The C horizon represents the geological deposit or parent material from which the true soil has developed. Weathering processes may be active in this horizon, but the influence of the soil forming processes is slight.

In descriptions of soil profiles reference is sometimes made to a D horizon. This represents a different geological deposit from that forming the overlying horizons.

For more detailed descriptions of soil profiles the various horizons may be subdivided into A_1, A_2, B_1, B_2, and so on. Transitional horizons can be indicated by combining the horizon symbols, for example A–B.

The Soil Landscape

The study of individual soil profiles is necessary for the description and classification of soils. However, it must not be forgotten that the natural soil has geographical attributes—it occupies a specific location on the earth and it has length, breadth, thickness, and topographic form. It has a characteristic native vegetation or, if cultivated, a predominant pattern of agricultural use. Other cultural features such as transportation and settlement may be influenced by the soil landscape.

The soil profile is the unit of soil classification and the soil landscape is the unit of soil mapping. In broad soil surveys or where the soil pattern is complex the individual soil landscape, representing a segment of a land form, cannot be shown separately on the soil map. Under such conditions it is necessary to map combinations or complexes of individual soil types covering a given land form. In Saskatchewan the soil association (catena), adapted from Ellis (4), is used to classify and map complex soil areas.

The Value of Pedology to Geological Studies

The term "geological studies" is used in the broadest sense and includes geological, geographical, geomorphological, and engineering studies dealing with the regolith.

Studies Involving Natural Soils

If soil profiles and soil landscapes form part of a particular study they should be described in pedological terms. Only in this way can use be made of available pedological information or the results of the particular study be applied to other soil areas.

In actual practice many studies by geologists, geographers, and engineers deal with the soil but ignore soil science. For example, some textbooks in general geology still speak of "transported soils," "residual soils," "limestone soils," following the type of classification in use before the time of Dokuchaiev. Flint (5), referring to calcareous glacial drift, indicates that in the

geologist's terminology the pedologist's A horizon is "soil," the B horizon "thoroughly decomposed chemically," and the C horizon is "leached of carbonates." Whatever is meant by these statements they do not refer to a true soil profile on calcareous parent material. Radforth (14), dealing with organic soils, prefers to use the term "organic terrain" and gives no indication that he consulted the pedological literature on these soils.

Similarly, engineers dealing with the irrigation or drainage of natural soils sometimes depend on an engineering classification alone and ignore the pedological classification and map of the soils. This policy has on occasion proved disastrous to the economic use of the land.

Other Studies of the Regolith

Pedology may also be useful to other investigations of the regolith in which the natural soil is not the main object of study. Assuming the geologist is familiar with the principles and methods of pedology, he can secure the most direct help from the soil map and accompanying report. The value of the soil map to geological interpretation in Saskatchewan has been discussed by Edmunds (3), and it may be stated here that the Departments of Geology and of Soil Science in Saskatchewan have long appreciated the relationship between their respective fields of study.

One of the most useful features of the soil map is that it represents a systematic coverage of a given area, at least in settled regions. This means that for studies of surface deposits and land forms the geologist need not cover the whole area in detail; the pedologist has already located and described the land forms, topography, and geological deposits (C horizons) in the course of classifying and mapping the soils. Hence the geologist can secure considerable information without studying individual soil profiles or their agricultural significance. However, he may gain additional information of geological value by studying the soil profiles.

The soil profile and its site reflect the features of the environment in which the soil has developed. Thus the soil profile may suggest the dominant type of vegetation, and indirectly the climate, of the site; also whether it is well drained, imperfectly drained, or poorly drained; whether there has been significant erosion or deposition; whether a change in environmental conditions has occurred since soil formation began; and finally, something of the potential use and agricultural productivity of the given soil.

The full value of the soil map can only be realized if use is made of the soil report. The latter deals with the classification, morphology, and composition of the soil profiles, and also includes information on the geology, climate, ecology, and cultural geography of the map area.

Information of the above nature is also useful to the highway engineer. He may have to remove or bury the original soil in order to build a road-bed; however, an examination of the soil profiles made in advance may provide valuable information on problems of drainage, salinity, colloidal behaviour, and other significant soil conditions. Vanderford (21) quotes a highway

engineer as stating that a thirty-two mile stretch of highway in one of the southern states was characterized by fine clay soils. To counteract the swelling of the clay several feet of fill were required. The soil map of this area, published later, showed that the highway could have been moved one mile and the clay soil avoided. If the map had been available earlier and had been used, $600,000 could have been saved.

The full value of pedology to other sciences can only be realized if geologists and related scientists become interested in pedological studies. Such interest is by no means general as yet. As expressed by Stamp (19), "To the geologist the soil is even a worse nuisance than the superficial drift deposits; it hides the rocks below and its presence may involve the necessity even of digging pits to see what is underneath." In their text on geomorphology Woolridge and Morgan (22) make the fantastic assertion that soils "have little to do with pure geomorphology and find no place in the following pages." On the other hand Thornbury (20) states that a knowledge of pedology is vital to the geomorphologist, and he refers to soil maps as "a much neglected tool."

Finally, it should be pointed out that one of the difficulties of applying pedology to other fields of science is the variable use made of the word "soil." Publications dealing with the interpretation of aerial photos, such as that of Frost and Mollard (6), make reference to "aerial soil mapping" and "soil patterns." In most instances what is interpreted is the pattern of soil forming factors—the geological deposits, land forms, topography, drainage, and vegetative cover.

Legget (12) has proposed the acceptance of the word "soil" to cover all unconsolidated deposits overlying the bedrock. He bases his proposal on two main statements: the first that geologists have long used the word in the same sense as the engineers, and the other that beyond the immediate C horizon the pedologist is not interested in the regolith. With regard to the first statement the long use of a particular term in a field of science does not mean it is correct today. The geological references quoted by Legett were published between 1815 and 1885, before the principles of pedology were established or before they were known to the authors. With reference to the depth at which the pedologist has no interest in the regolith, the pedologist must politely but firmly decline to have that point decided for him. As Robinson (15) states, "the pedologist claims the right to study the pedogenic processes in their widest significance. The domain of pedology can only be defined by the natural limits of enquiry and may come to engross a considerable portion of dynamic geology. Indeed, studies of contemporary pedogenic processes may be expected to throw light on many of the problems of sedimentary petrology." To be more specific, the pedologist may be interested in the regolith (and even in the bedrock) for several reasons: the deposits may contain materials such as fine clay which owe their origin to an earlier cycle of soil formation; buried soils may occur well below the surface; fluctuations in the water table may affect the present soil profiles;

and deeply weathered rock in tropical regions may become exposed and form the parent material of new soils. As Berry and Ruxton (2) have quoted in their paper, the pedologist seldom looks "far enough down" or the geologist "far enough up."

The Geological Sciences as an Aid to Pedology

The potential contributions of pedology to the geological sciences have been stressed because it is felt they have been neglected by the geological scientists. This is strange in view of the fact that all of the leaders mentioned in connection with the development of pedology, Dokuchaiev, Sibirtsev, Glinka, Hilgard, and Marbut, were geologists by training. In this sense geology may claim to have founded the science of pedology.

Today most of the support for soil science comes from agricultural colleges and governmental departments of agriculture. This is because soil science has demonstrated its practical value to crop production and to agricultural use of land. This most useful association has some drawbacks to fundamental pedology: the pressure of official agricultural work makes it difficult to secure time for pedological research and there is a tendency, particularly in governmental departments, to emphasize the practical value of soil surveys and to neglect fundamental pedology.

It is believed that the geological sciences can further the development of pedology in several ways: by making use of pedological information; by direct contributions to geological phases of pedological research; and by seeing that students of geology and allied sciences are introduced to the science of pedology. This last suggestion could be adopted with little difficulty by those universities where the faculty of agriculture (and therefore the department of soil science) is part of the university and is situated on the campus. There are other Canadian universities in which the faculty of agriculture is not represented or at least is not situated on the main campus. In such institutions it is suggested that departments of geology might add qualified pedologists to their staffs. This arrangement, besides providing instruction to students, would demonstrate that the field of pedology is not limited to its agricultural applications.

To conclude, the pedologist welcomes an opportunity to introduce his field of study to the geologist, and would say, with the shepherd in *As You Like it*:

> Go with me: if you like upon report
> The soil, the profit and this kind of life,
> I will your very faithful feeder be. . . .

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